PRIME POWER: FILLING THE ARMY'S ELECTRIC POWER GAP

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LMI

Executive Summary

PRIME POWER: FILLING THE ARMY'S ELECTRIC POWER GAP

The Army cannot be sure whether it has enough prime power generators to provide electricity during wartime. It has reason to believe it may not.

The uncertainty – the possible deficiency – should not be tolerated. Prime power is essential. The alternatives will not suffice. Commercial utilities are not available everywhere and are too vulnerable in wartime. Tactical generators consume too much fuel, demand too much maintenance, and wear out too fast for general usage.

The barrier to overcoming the problem is the Army's inability to produce a sound estimate of the requirement. The current estimating method is based on an outdated and incomplete mission statement for prime power generators and employs a single, outdated, kilowatt-per-person planning factor. The mission should be restated to include:

- Overseas, provide reliable, mobile, and resource-efficient power to groups of Army units and essential installations behind the front combat zone.
- In the United States, support large, rapid population increases in Army installations during mobilization.
- In the United States, provide emergency power to Army and other critical installations when commercial power distribution is disrupted.

The requirements calculation should, to be more reflective of real-world forces, be based on scenario-specific simulation of peak-time power consumption by selected Army units and installations.

These changes should be implemented by the Army's Engineering and Housing Support Center. Only then will the Army be in a position to rectify any prime power deficiencies.

CONTENTS

Page

Executive Summary iii

Chapter 1. The Army's Need for Prime Power 1-1

Conclusions 1-1
Recommendations 1-2
Report Organization 1-3

Chapter 2. Electric Power for the Modern Army 2-1

Tactical Generators 2-2
Commercial Power 2-2
Prime Power 2-4
The Benefits of Prime Power 2-6

Chapter 3. Prime Power's OCONUS Mission 3-1

OCONUS Power Requirements 3-1
Army Theater Organization 3-2
Bases and Installations 3-2
Commercial Power and Host Nation Support 3-3

Chapter 4. Prime Power's CONUS Mission 4-1

Mobilization Surge 4-1
Interruption of Commercial Power 4-3

Chapter 5. Estimating Prime Power Requirements 5-1

Current Approaches for Estimating Generator
Requirements 5-1
Proposed Model Approach 5-4

Appendix A. Prototype Prime Power Requirements Model .... A-1 – A-6

Appendix B. Calculating Electrical Loads .... B-1 – B-8

CONTENTS (Continued)

		Page
Appendix C.	Worldwide Electric Power Frequency and Voltage Standards	C-1 – C-5
Appendix D.	Existing Army Prime Power Assets	D-1 – D-3
Appendix E.	Suggested Revision to Army Regulation 700-128	E-1

CHAPTER 1

THE ARMY'S NEED FOR PRIME POWER

CONCLUSIONS

Energy in the form of electric power is as critical to the modern Army as energy from diesel fuel or jet fuel. Electric power drives a multitude of essential equipment, ranging from radar sets to security lighting. The Army obtains electric power from three sources: tactical generators (TacGen), commercial power, and prime power generators.

Those three electric power sources vary in mobility, reliability, and resource-efficiency. TacGen are the most mobile sources but the least resource-efficient; commercial power – where available – is the most resource-efficient but is the least reliable in wartime. Prime power fills the gap between TacGen and commercial power by providing mobile yet reliable and resource-efficient power.

In peacetime, the Army purchases most of its electricity from commercial utilities. In wartime and military emergencies, however, Army units must be capable of mobile self-sufficiency. Those units, therefore, will need either TacGen or prime power generators, depending on the required degree of mobility.

Tactical generators are the only feasible source of electric power in the Forward Combat Zone (FCZ) where a high degree of mobility is critical. While TacGen have the advantage of extreme mobility, they are more costly in terms of critical resources – diesel fuel, manpower, and spare parts – than prime power.

Prime power generators serve two essential wartime functions in the Rear Combat Zone (RCZ) and the Communications Zone (COMMZ), where units move less frequently and the tendency for multiple-unit base formation is more likely. First, they are a source of reliable, mobile electrical power for installations and concentrations of headquarters and support units, and second, they provide insurance against the loss of commercial power.

Commercial power requires the fewest resources of any Army power source – when and where it is available. However, even in areas of the world in which commercial power is plentiful and reliable in peacetime, it is vulnerable to damage during war. Electric power cannot be economically stored in appreciable quantities. Therefore, when units and installations depend upon commercial power and the commercial distribution system is damaged or service is interrupted for any reason, essential equipment is unable to operate. Prime power makes such units and installations more self-sufficient and less vulnerable to enemy damage at a lower cost in critical resources than TacGen.

RECOMMENDATIONS

We recommend that the Directorate of Prime Power and Emergency Operations of the Engineering and Housing Support Center (EHSC), U.S. Army Corps of Engineers, revise the Prime Power Program mission statement to include the following three major wartime and emergency functions of prime power:

- Overseas, prime power should provide reliable, mobile, and resource-efficient power to concentrations of Army units and essential installations in the rear combat and communications zones. Even in countries where commercial power is widely available in peacetime, prime power provides more reliable war-fighting power than highly vulnerable commercial generation and distribution systems.
- In the United States, prime power should provide additional power to support large, rapid personnel increases at U.S. Army installations in the event of mobilization.
- Also in the United States, prime power should be available to provide emergency power to Army and other critical installations if the commercial power grid is damaged by, for example, saboteurs or terrorists.

The Directorate of Prime Power must calculate the required level of pre-positioned prime power assets required to meet those essential missions. We recommend that the Directorate calculate those requirements using the methodology described in this report, which bases generator requirements on electricity-consuming equipment requirements rather than unit populations.

To implement our recommendation, the Directorate should distribute the microcomputer requirements model we have developed – The Prime Power Requirements Model (PPRM) – to the relevant Major Commands (MACOMs) within

the Army. After each MACOM has input the required data consisting of base and installation scenarios, the Directorate should then use the model output as the basis for its equipment requirements.

We further recommend that the Directorate of Prime Power contact the Federal Emergency Management Agency (FEMA) to participate in future FEMA electric power exercises. Doing so will enable EHSC to measure the effect on Army installations of damage to the domestic commercial electric power infrastructure – the grid. Neither DoD nor any of its components has previously participated in FEMA exercises.

REPORT ORGANIZATION

In this report, we examine the wartime and emergency missions of the Army's Prime Power Program. We also propose a new methodology for calculating the prime power requirements arising from those missions. We summarize our overall recommendations and conclusions in this chapter. In Chapters 2 through 5, we provide the detailed findings that support our conclusions.

In Chapter 2, we examine the Army's overall electric power requirements and the advantages and disadvantages of different power sources. Chapter 3 focuses on prime power mission outside the continental United States (OCONUS) while Chapter 4 discusses the mission within the continental United States (CONUS). Chapter 5 addresses the measurement of electric power requirements and specifically, the methodology that we have developed for calculating prime power requirements.

Appendix A describes the Prime Power Requirements Model, an implementation of our requirements methodology. Appendix B provides details on electrical terminology and the calculation of connected and peak loads. Appendix C describes voltage and frequency conversion and lists worldwide electric power frequency and voltage standards, and Appendix D describes the Army's existing prime power assets. Appendix E provides a suggested revision to Army Regulation 700-128.

CHAPTER 2

ELECTRIC POWER FOR THE MODERN ARMY

Electric power is as indispensable to the modern Army as it is to the private economy; like diesel fuel or jet fuel, it is a critical military energy resource. Weapon systems, logistics systems, and other support systems depend upon electric power to operate. It powers communications equipment, security and regular lighting, computers, hospital equipment, food refrigeration, environmental control equipment, and test and repair equipment to name a few. For example, the Army owns and operates about 30,000 lighting sets and 13,000 air conditioners.[1] Sophisticated electronic equipment not only requires electricity for its own power, it also needs electrically-powered climate-control equipment to make sure those sensitive electronic devices perform reliably.

The Army also relies upon electric-powered equipment owned and operated by others. Its lines of communication depend upon the reliable operation of such host nation assets as electric cranes at ports of debarkation and a profusion of equipment at support facilities operated by host nations, such as maintenance depots, petroleum fuel pumping stations, and the like.

To meet all those needs, the Army's electric power sources must be reliable and supply power that meets minimal quality specifications. The Army can either obtain electric power from commercial electric utilities or it can generate its own. In peacetime, the Army purchases most of its electricity from commercial utilities. In wartime and other military emergencies, however, many Army units must be self-sufficient and highly mobile. Therefore, the policy of the Army's Training and Doctrine Command (TRADOC) dictates that each Army unit at Corps level and below should carry sufficient generating equipment to enable the unit to fulfill its potential combat mission without resorting to outside power.

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[1] Higgins, M.S., et al. *An Analysis of Future U.S. Army Tactical Electric Power Requirements*, BDM Report MCL-86-0949-TR. March, 1987. p. I-1.

TACTICAL GENERATORS

Ideally, Army units meet the TRADOC requirement by possessing enough TacGen to meet the electrical requirements of their combat mission. Tactical generators are generally the only feasible source of electric power in the FCZ where tactical mobility and independence from commercial utilities is critical. Tactical generators are small, extremely mobile, diesel-powered generators. The generating capacity of standard Army TacGen ranges from about 5 kW to 100 kW, although some larger units also exist. TacGen are either integral to the equipment they power or are small enough to be carried by or pulled behind tactical vehicles.

TacGen's high degree of mobility imposes significantly higher costs in terms of critical resources – diesel fuel, manpower, and spare parts – than other sources of electricity. TacGen consumes more fuel and requires more attention than larger generators, and operates for a shorter average time between overhauls. In general, electricity generation is highly subject to economies of scale: the bigger the generator, the cheaper and more reliable it tends to be as long as it is operated at or near capacity.

COMMERCIAL POWER

While commercial power consumes fewer Army resources than TacGen, it is vulnerable in wartime (and even in peacetime). Electric power plants and the grid, including high voltage transmission lines, are high-value targets for enemy air strikes and behind-the-lines sabotage. Moreover, in many parts of the world, the electricity generated, even in peacetime, does not meet minimal quality and reliability standards.

In peacetime, commercial utilities are the most cost-effective source of electric power to Army installations, at least in places where such power is currently available and reliable. Because of its apparent ready availability and low use of Army resources (including airlift and sealift capacity), Army planners assume that many CONUS and OCONUS installations, including temporary concentrations of headquarters and support units, will continue to receive commercial power in wartime too.

The vulnerability of commercial power in war, however, makes total reliance on that source a risky strategy. Despite that fact, neither DoD nor the Army appears

to have studied the wartime vulnerability of commercial utilities in any depth. FEMA has gamed the U.S. grid in peacetime and has concluded that significant CONUS power losses would result from a well organized campaign of sabotage.[2]

A break anywhere in the commercial grid will interrupt power to one or more users; the closer to the generating plant that break occurs, the larger the number of users affected. An electric grid consists of electric generating plants together with a system of high-voltage transmission and lower-voltage distribution lines carrying power to the end users. Large transmission substations connect the high-voltage transmission lines with the more numerous lower-voltage distribution lines; transmission lines also connect power plants with each other to allow pooling of power. Distribution lines terminate at small distribution substations which feed additional low voltage lines, with line transformers reducing voltages for the final users. Some large users, both military and civilian, are connected directly to high-voltage transmission lines via their own transmission substations.

FEMA found that major transmission substations are the most vulnerable element in the CONUS grid. They are relatively easy to disable and strategically located to cut off numerous users. Moreover, very little replacement equipment is held in reserve and manufacturing replacement equipment is a lengthy process. Reconfiguration of the grid to get around damaged transmission substations is possible, but only to a limited extent. Smaller distribution substations are equally vulnerable to sabotage but they affect fewer users and are more easily replaced.

With extensions, FEMA's findings are also applicable to OCONUS wartime vulnerability: transmission substations will remain vulnerable to sabotage and, in addition, electric generating plants will be vulnerable to air strikes. Power plants are large, easily visible targets with large heat signatures. The high-voltage transmission system is somewhat less vulnerable to air strikes but is as vulnerable to sabotage in war as FEMA found it in peace. The low-voltage distribution system, while less vulnerable, affects fewer users. Since distribution substations offer small targets, damage to the distribution system is likely to be proportional to damage to the underlying industrial base. That is, at the local level, electric supply and demand will be reduced in equal increments. The main threat is to power stations

[2] *Final Report, Energy Emergency Simulation*. Energy Vulnerability Assessment Subgroup, Interagency Group on Energy Vulnerability, FEMA. December 1987.

and main transmission systems; if they are destroyed, local distribution systems are useless, no matter how functional they remain.

Our findings regarding the vulnerability of OCONUS commercial power in future wars are consistent with World War II experience. At that time, the Germans were worried by what they saw as the vulnerability of their electrical infrastructure.[3] According to Albert Speer, the Nazi Minister for Armament and War Production, "The destruction of the power plants would be the most radical measure [for inflicting damage] as it would at once lead to a breakdown of all industry and public life. It is the only field, besides [natural] gas, where no reserves which are likely to postpone the effects for some months can be stored." Wartime records indicate that the Germans considered 41 generating plants and 9 large transmission substations – about one-quarter of total capacity – to be particularly susceptible to Allied attack. High-voltage transformers (in transmission substations) were frequently lost due to their flammability. Transmission lines were not considered profitable targets, however.

Two factors reduce the vulnerability of a particular grid. First, a decentralized grid consisting of a large number of small plants will be less vulnerable than one with fewer large plants. Second, a grid with excess capacity is less vulnerable than one that is at or near capacity.

In addition to the problems of combat and sabotage, commercial power in many less developed nations is unavailable, unreliable, or of inadequate quality even in peacetime. In many areas, extensive power grids do not exist; where such grids exist, brownouts and even blackouts are not uncommon. Moreover, dependence on commercial power makes it possible for hostile elements or even host governments to hinder Army operations by cutting off power. Some Army overseas commands have installed prime power generators to mitigate such potential shutdowns of commercial power to U.S. installations.

PRIME POWER

The Army's third source of electric power – prime power – bridges the gap between TacGen and commercial power. Prime power is more resource-efficient than TacGen and more reliable – because self-contained – than commercial power.

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[3] *United States Strategic Bombing Survey; Utilities Division Industry Report.* pp. 46–54.

Prime power consists of larger generators that supply 500 kW or more with compatible transformers and distribution equipment. Table 2-1 compares the operating characteristics of the three sources of electric power available to the Army. Each has its advantages and disadvantages.

TABLE 2-1

ARMY POWER SOURCES

Power source	Power output (kW)	Mobility	Resource-efficiency	Vulnerability	Maintenance required[b]	Noise & temperature signature[c]
TacGen	5 – 100	High	Low	Medium	High	Medium
Prime power	500 – 1,500	Medium	Medium	Medium	Medium	Low
Commercial power	Full range[a]	None	High	High	Low	None

[a] Maximum power available depends upon transformers and cable to site.
[b] Including refueling.
[c] At user's site.

Prime power equipment is distinct from secondary, or standby, power-generation equipment that is used when commercial power fails. Prime power is the main power source whereas standby generators ensure continuous operation to critical facilities such as hospitals for brief periods until the restoration of power.

While the commercial definition of prime power covers all nonutility generators, the Army distinguishes between TacGen and prime power generators. The latter are trailer-sized and require more set-up time than TacGen.[4] TacGen units power fewer items of equipment and require little or no time to connect because they employ modular plug-in distribution systems known as Distribution and Illumination Systems, Electrical (DISE). Those modular systems can connect items up to 300 feet from the generator. A prime power generator normally employs a more widespread distribution system consisting of transformers and electrical cable to deliver power to the many items of equipment it serves. Connecting all end-users to a single prime power generator that supplies 750 kW takes about a week;

[4] New prime power generators will be smaller; see Appendix D.

dismantling the system takes about the same amount of time. The Army is looking into ways to reduce set-up/take-down times.

THE BENEFITS OF PRIME POWER

Prime power assets are superior to TacGen as a power source when units do not move frequently. Prime power generators use less diesel fuel and manpower per kW than TacGen, last longer between overhauls, and produce more reliable power. Manpower savings result from centralized control of fewer generators, less maintenance, and more-centralized and less-frequent refueling. A prime power generator that delivers 750 kW costs about 10 cents per kWh to operate compared to 50 cents per kWh for a TacGen unit that delivers 100 kW.

Table 2-2 clearly demonstrates that prime power uses fewer resources than TacGen; it compares the operating parameters of a prime power generator providing 750 kW with those of a mix of 55 TacGen systems providing the same amount of power. The table summarizes the results of the 1985 Bright Star exercise in which prime power generators were substituted for TacGen.

TABLE 2-2

COMPARISON OF GENERATOR SYSTEMS: BRIGHT STAR '85

	Prime power system	Tactical generators
Generator sizes	750 kW	5 kW – 100 kW
Number of systems	1 system	55 systems[b]
Weight of generators	38,500 lb	132,400 lb
Fuel consumed	9,500 gallons	36,300 gallons
Maintenance required	1,318 man hours	6,052 man hours
Failures[a]	2 failures	7 failures

[a] Within 380 operating hours.

[b] Totalling 750 kW.

Figure 2-1 demonstrates the cost-effectiveness of prime power versus TacGen. The figure compares the operating costs for prime power generators with those of TacGen of different sizes; operating costs are normalized to a 1,000-kW load. The graph makes the conservative assumption that prime power is deployed in *addition*

to TacGen rather than in place of them. That is, TacGen units are assigned for use when tactical mobility is required and when the prime power distribution system is being set up or taken down. The combined procurement and operating costs of the generators producing 500 kW and 750 kW, therefore, is added on top of the TacGen procurement and operating costs since it includes the investment in all systems. Nevertheless, prime power still decreases the expense and logistic burden of TacGen by increasing the replacement interval. Assuming that TacGen requires a major

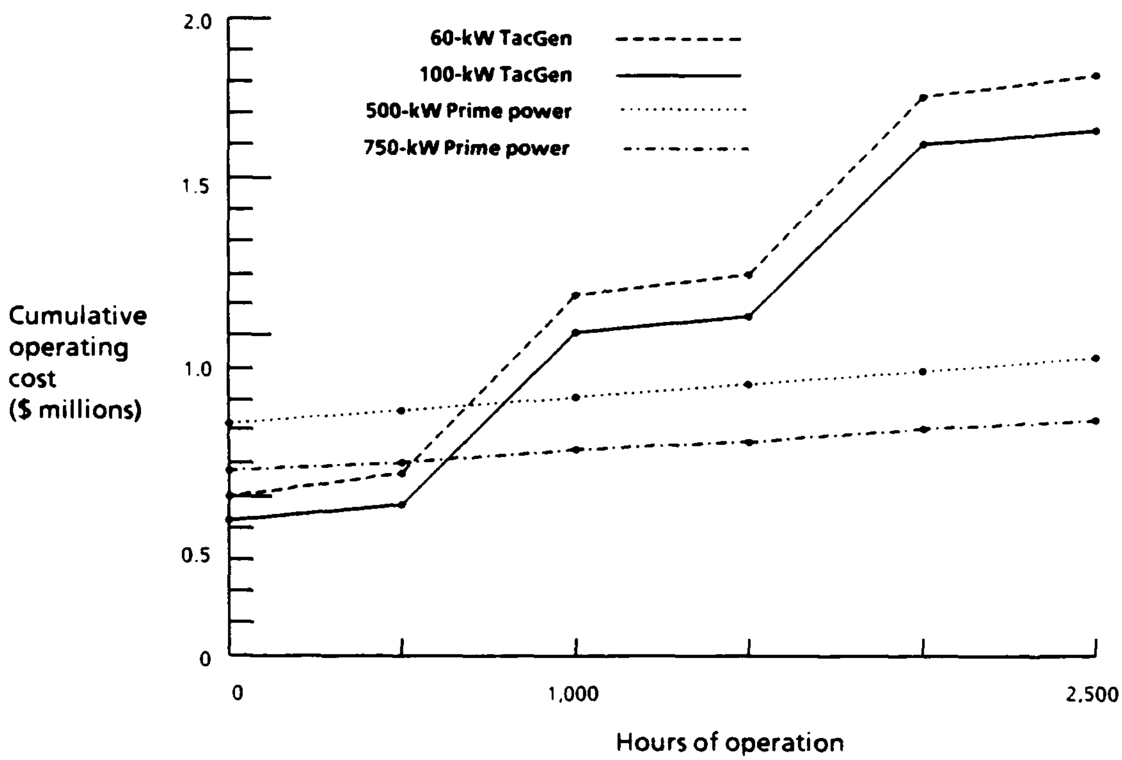

FIG. 2-1. GENERATOR OPERATING COSTS AT 1,000-kW LOAD

overhaul after 1,000 hours of operation, prime power proves more cost-effective under sustained operations. Moreover, when TacGen is used instead of prime power by units posted to the COMMZ or the RCZ, those generators have fewer reliable operating hours remaining for their eventual critical missions in the FCZ and RCZ.

Prime power is also preferable to commercial power when the latter is likely to be interrupted by enemy damage or to be otherwise unavailable. While commercial power uses the fewest Army resources of any power source, the Army cannot depend

upon its availability. In some instances, at echelons above Corps as well as installations such as ports of debarkation and heavy maintenance facilities, TacGen is not even available as an alternative to commercial power and, in many cases, would be inadequate even if it were. In such situations, prime power is the only reliable alternative for electric power.

CHAPTER 3

PRIME POWER'S OCONUS MISSION

During military operations in Army theater and contingency situations, the Army will require electric power in areas ranging from its ports of debarkation through to the FCZ. TacGen, because of its superior mobility and independence, will likely supply most of the power in the FCZ. Elsewhere, the Army will rely upon a combination of prime power, TacGen, and commercial power.

The choice of an appropriate power source for an Army theater in wartime depends upon how well each source meets the Army's power requirements. The most critical factors are the degree of user mobility, the wartime availability of the power source where it is needed, and its rate of resource consumption.

In this chapter, we describe the OCONUS mission of prime power; in Chapter 5, we describe how to estimate that requirement.

OCONUS POWER REQUIREMENTS

We conclude that prime power's mission is to supply electric power to the following critical users during war and contingency situations.

- Prime power is needed by concentrations of Army units that move less frequently than tactical users, when and where host nation commercial power is unavailable or unreliable due to the likelihood of war damage or other factors.
- Prime power is also needed to ensure the continuous operation of critical installations that depend on electric power. Those installations can be under the control of either the U.S. Army or a host nation. The prime power assets required to power those installations can, likewise, be provided by either the U.S. Army or the host nation.

During an OCONUS military emergency, prime power offers more resource-efficient power than TacGen together with greater mobility and reliability than commercial power. In addition, prime power preserves TacGen assets for those occasions when tactical mobility is required. Prime power thus expands the Army's

ability to move quickly to any location while simultaneously conserving three vital resources: fuel, manpower, and TacGen.

ARMY THEATER ORGANIZATION

The Army theater is organized into the combat zone (CZ), which contains the combat forces and the tactical logistics units, and the COMMZ, which is located behind the combat zone and contains resources to sustain the tactical units. The combat zone is further subdivided into the RCZ and the FCZ. In Europe, Great Britain and the Benelux nations – Belgium, The Netherlands, and Luxembourg – constitute the COMMZ, while the Federal Republic of Germany (West Germany) constitutes the FCZ and RCZ. The organization is important because it determines the degree of mobility required by Army units and consequently, which electric power source is likely to be appropriate.

BASES AND INSTALLATIONS

Potential OCONUS users of prime power are located in the COMMZ and RCZ. They comprise concentrated groupings of Army headquarters and support units (bases), Army *installations*, and host nation installations.

Army planners assume that certain combat service support units with associated or complementary functions will concentrate in temporary bases located behind the combat zone. Though temporary, such bases are usually relatively stable, staying in place for more than 2 weeks. Other concentrations of electric users include installations such as intermediate staging facilities, maintenance depots, and ports of debarkation. Those installations consist of Army units and, where host nation agreements exist, host nation support.

Such installations and concentrations of units are rarely found in the FCZ because they offer a concentrated target to the enemy. Behind the FCZ, however, bases and similar assemblies provide the offsetting advantages of more efficient provision of support to other units with more easily patrolled perimeters and concentrations of utilities.

Prime power is a more effective source of power in the COMMZ and RCZ than either TacGen or commercial power. It is less vulnerable and more mobile than commercial power and it is more resource-efficient than TacGen. Moreover, TacGen will simply be unavailable for most support installations, particularly those owned

and operated by host nations. If, for example, power fails at a maintenance depot, a whole range of essential support services becomes more difficult, if not impossible, to obtain.

In the FCZ, where damage to the grid will be highest, TacGen will be the electricity source of choice. During wartime and other military emergencies, most Army units will deploy away from their home installations and other fixed facilities. In particular, tactical units deployed to the FCZ must be highly mobile and cannot rely on the grid for power even if its integrity is maintained.

COMMERCIAL POWER AND HOST NATION SUPPORT

Prime power, however, provides more resource-efficient, reliable power for bases and installations in the COMMZ and RCZ than TacGen; it also reduces the risks inherent in dependence upon commercial power. The use of TacGen as the primary power source for bases and installations consumes critical resources – diesel fuel, maintenance, and the TacGen units – more rapidly than the use of either prime power or commercial power. Reliance on commercial power in the COMMZ and RCZ exposes the Army's operations to the risks of damage to the commercial grid. In many areas, moreover, commercial power is simply unavailable in either war or peace; prime power assets assure the Army's ability to operate its electrical equipment effectively in such locations.

In the European theater, the most highly developed area in which the Army plans to operate, Army planners currently assume a high level of host nation support functions and installations for many logistics requirements. Commercial electric power is only implicitly included among those logistics requirements, as necessary to the functioning of most such host nation support functions and installations. However, power is not specifically mentioned in most formal international agreements. Elsewhere in the world, with some notable exceptions (including Korea and Japan), the commercial grid is less extensive and thus power will be less readily available as well as less reliable.

The extent to which the U.S. Army can depend upon electric power from the European or other host nations depends upon the accuracy of current estimates of host nation support and estimates of the likely extent of damage to commercial power assets – power plants, substations, and transmission lines.

U.S. policy is to seek support from the host nation before creating and equipping deployable units to supply the required capability itself. That policy enables limited U.S. resources to be concentrated in other important areas and reduces airlift and sealift requirements.

In Europe, the Army assumes that host nations will provide 80 to 100 percent of total logistics support requirements. The Engineer Study Center of the U.S. Army Corps of Engineers is currently working to validate the amount of installation support that the Army can reasonably expect. In the meantime, many host nation planning estimates remain unsupported.

European host nations will support U.S. efforts in all of the activities required to receive U.S. forces at ports of debarkation, to move them to the bases of operation, and to establish operational capacity at those bases. Existing host nation support agreements cover partial to total assistance in transportation, petroleum logistics, installations, and overall logistics support and services.

European host nation support agreements range from broad country-to-country agreements to more specialized agreements on specific types of support. Those agreements plan for electrical requirements only insofar as they are components of other requirements. Support planning in the NATO countries is coordinated by the Senior Civil Emergency Planning Committee through eight planning boards and committees. One of those committees – the Petroleum Planning Committee – concentrates on the logistics of petroleum fuels; none, however, focuses exclusively on the demand for and supply of electricity in wartime. While electric power is needed by everyone for pipeline pumping stations, trains, and industry in general, it is apparently taken largely for granted.

In Europe, the Benelux countries constitute the COMMZ in a European wartime scenario, the location with the largest concentration of fixed military electricity users. Since the Benelux countries are net exporters of electric power in peacetime, NATO planners assume that sufficient power will be available to support host nation and Army requirements in that area. Moreover, the commercial grid is fairly dense in most of western Europe, including the Benelux, so that peacetime commercial power is available in most locations.

Electric power requirements for U.S. Army combat service support units in the European COMMZ are presently the responsibility of the host nation. U.S. Army

base and facility support requirements, specifically including electric power, are included in the Statement of Requirements (SOR) document which is provided to the host nation by the U.S. Army. The current planning factor for bases in the COMMZ is 100 kW per day; certain maintenance units with higher than normal power loads have included those higher requirements in their SORs.

As we discussed in the previous chapter, however, European commercial power is vulnerable to combat damage. In the FCZ, transmission lines, substations, and power plants are likely to be damaged by both friendly and unfriendly fire. The threat of damage in the RCZ and the COMMZ depends on the intensity of combat and the extent to which the enemy is capable of inflicting damage in the rear either by enemy air strikes or sabotage.

In the RCZ, where less mobility is required, commercial power will also be vulnerable. Thus, in a medium to high-intensity conflict, prime power will provide more reliable support than commercial power. It will also provide a degree of mobility and independence without using as many resources as TacGen.

Under scenarios in which conflict intensity in the RCZ and the COMMZ escalates to an extremely high level, however, Army support units will become as mobile as tactical units. In such extreme scenarios, therefore, even prime power will give way to TacGen. In that event, however, even TacGen (and its necessary logistics support) will be insufficient to meet requirements.

In addition to its vulnerability, commercial power introduces interconnectibility problems. For example, the standard electrical frequency for alternating current (AC) in all the nations of Western Europe and in most other nations is 50 Hz.[1] The U.S. standard for AC is 60 Hz. The Army is moving toward dual-switched equipment that can use either 50- or 60-Hz current, but without frequency converters, many 60-Hz items will not operate properly on European or other host nation commercial power even when such power is available. Standard commercial voltages vary even more than AC frequencies and often only with transformers can U.S. Army equipment connect to local electrical distribution networks.

[1] Appendix C discusses frequency and voltage conversion and also lists electrical standards throughout the world.

The Army's prime power requirements of necessity include frequency conversion equipment, transformers, and switchgear in addition to generators. Chapter 5 discusses the methods we have developed for measuring those requirements. In the next chapter, we discuss the CONUS mission for prime power.

CHAPTER 4

PRIME POWER'S CONUS MISSION

Prime power's CONUS mission is to supply emergency electric power under the following war and contingency situations:

- Prime power will augment commercial power to U.S. Army installations that undergo large and rapid population increases during mobilization.
- Prime power also ensures rapid restoration of power to Army installations when commercial power is disrupted.

In this chapter, we address the CONUS mission for prime power. As in the previous chapter, we do not quantitatively assess the CONUS requirement since we have designed the Prime Power Requirements Model to provide that.

MOBILIZATION SURGE

Certain domestic Army installations are earmarked as mobilization stations in the event of a war or other major military emergency. During mobilization, active Army components will vacate those installations and be replaced by reservists, trainees, and, in a major emergency, draftees. The mobilization installations will prepare those new troops to be transferred to the war zone. Despite the transfer of most active Army components, the populations of such installations will increase significantly.

The Army CONUS mobilization installations are divided between TRADOC and Forces Command (FORSCOM), which have developed mobilization master plans for each installation. The plans generally maintain that sufficient electrical power will be available to meet surge requirements during mobilization. Each master plan examines the installation's mobilization requirements and the means for meeting them, including the electricity supply. The quality and reliability of those master plans vary; some are very detailed, while others are sketchy.

While commercial power should be available to meet most domestic mobilization requirements, prime power will nevertheless remain a potent backup source to guarantee sufficient capacity during troop build-up. During peacetime,

prime power serves as a source of electricity during both planned and unplanned outages at domestic Army installations. Prime power can and should serve the same purpose during mobilization. While a prime power unit is not needed for every mobilization installation, the Army should preposition prime power units at two or three strategic locations throughout the United States, ready for rapid deployment when needed.

We examined Fort Indiantown Gap, Pa., in detail because it provided a limited test of the demands of mobilization when it served as a processing center for more than 19,000 Cuban refugees in the summer and fall of 1980. In addition to the influx of refugees, the installation also received additional military and civilian personnel. Despite the large increase over its normal complement of about 120 military and 520 civilian personnel, Fort Indiantown Gap was able to meet all of its electrical demands without increasing capacity.[1] The installation experienced two temporary power outages, however.

Fort Indiantown Gap's mobilization master plan states that "... Metropolitan Edison [the local power company] has indicated that this [projected] demand level could be met, and that it could be provided over existing lines at transmission voltages."[2] (Since the plan is classified for official use only, we cannot cite its quantitative findings on past electricity consumption or projected mobilization consumption.)

Fort Indiantown Gap's experience with its population surge demonstrates that demand for electrical power does not increase in a direct ratio with the number of people working on an installation. The fort contains a large number of unoccupied World War II vintage barracks, and filling them did not significantly increase the installation's peak load. In the first place, while air conditioning is a major electricity consumer, none of the old barracks is air conditioned. Some base office buildings are air conditioned, but their utilization did not change significantly with the increase in population. The major addition to the electrical load was the rental of several refrigerated vans for food storage. Apart from that additional load, however,

[1] The population of Fort Indiantown Gap normally increases to nearly 6,000 in the summer when it houses reservists.

[2] *Final Mobilization Master Planning Report; Fort Indiantown Gap, Pennsylvania.* Higginbotham and Associates. CO. 1984. pp. 3 – 15.

the peak load did not increase significantly. As the base engineers observed, the total connected load acted as a ceiling on electric power use.

During mobilization, installations will operate on an austere basis, if necessary, to conserve electricity and other resources. Bare-bones requirements will primarily be for food refrigeration, lighting, medical, and administrative equipment. Air conditioning – a big electricity consumer – can be limited to climate control for sensitive equipment.

Without prime power, the amount of power available for an installation during mobilization is limited by the size of the existing connection to the commercial grid. In addition, although Army installations have emergency generators to power medical, communications, and other critical facilities, those generators produce only a fraction of normal peak demand and are not designed to operate on a sustained basis. Fort Indiantown Gap, for example, has seven emergency generators that produce less than 10 percent of peak power requirements.

INTERRUPTION OF COMMERCIAL POWER

The second potential mission for prime power is to support peacetime operations as well as mobilization plans in the face of loss of commercial power to one or more domestic installations. All Services are currently examining the question of energy security. The Air Force has developed back-up energy systems to maintain mission-essential operations even during such a cutoff. The other Services, however, have not gone as far, partly because they do not consider themselves to be as dependent on outside electricity as is the Air Force.

The Army places a premium on mobility, and many Army organizations, particularly echelons below Corps, have their own TacGen available for emergency use. However, TacGen cannot be easily or directly linked to power equipment in fixed facilities.

FEMA has found that the U.S. power grid is vulnerable to sabotage. A concerted effort by a few saboteurs or terrorists would produce relatively severe disruptions. While total power outages are unlikely, severe brownouts are possible. Without prime power as a back-up source, such disruptions will jeopardize the Army's readiness.

CHAPTER 5

ESTIMATING PRIME POWER REQUIREMENTS

EHSC is responsible for defining and estimating the Army's total prime power requirement in the continental United States and overseas for emergency uses and wartime scenarios. As an aid for making this assessment, we have developed the PPRM computer model (the Prime Power Requirements Model), that estimates requirements by simulating peak loads for Army Tables of Organization and Equipment (TO&E) units and fixed installations under differing scenarios. The methodology is based on the electrical characteristics of the electricity-consuming equipment, users' load profiles, scenario inputs, and expected host nation support. Appendix A discusses the model in detail.

CURRENT APPROACHES FOR ESTIMATING GENERATOR REQUIREMENTS

The Army's *existing method of estimating prime power requirements* is unsatisfactory. It is based largely on a single Joint Chiefs of Staff (JCS) electrical planning factor of 0.7 kW per person.[1] Hospital facilities use a factor of 1.6 kW per bed. One shortcoming of the JCS factors is that they ignore other important determinants of power demand: connected load, environmental conditions, and operating profiles. In addition, even when we must ignore the other determinants – due to lack of data, for instance – better statistical estimators exist than a simple average of kW per person per installation.

While the JCS population factor derives from OCONUS wartime experience, it is based on a severely limited sample, involves questionable adjustments, and is an average value with wide dispersion. The factor is the average of peak electric power usage – after adjusting actual peak usage upward – at seven Army installations in Vietnam in 1968.[2] As Table 5-1 illustrates, the standard deviation of 0.51 kW per person within even that limited sample is very high compared to the average of 0.67 kW per person per installation (after adjustment), indicating that the average

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[1] *Army Field Manual 101-10-1*, pp. 1 – 43.

[2] *Electric Load Data Seven U.S. Army Bases*, Office of the Chief of Engineers, Department of Army Contract No. DACA-73-68-C-0014. Keller & Gannon Consulting Engineers, May 1969.

by itself is a poor forecasting tool. Actual power usage varied from 0.12 kW per person at a brigade base camp to 0.92 kW per person at a command facility. (The hospital had a peak usage of 1.81 kW per [assigned] person, but only 1.45 kW per bed.) The data, while limited, indicate that power usage is lower among combat units than among command and support units. More recent experience at Bright Star 1985 reinforces that conclusion; despite a population of 5,000, the peak load during that exercise never exceeded 450 kW, yielding a population factor of 0.09 kW per person.

TABLE 5-1

PEAK ELECTRIC POWER USE IN VIETNAM, 1968

Installation type	Location	Actual kW/person	Adjusted kW/person
Evacuation hospital	Pleiku	1.81	1.81
Command facility	Long Binh	0.92	0.92
Logistics support base	Cam Ranh Bay	0.44	0.44
Infantry division base camp	Camp Enari, Pleiku	0.21	0.35[a]
Army aviation base	Phu Loi	0.21	0.59[a]
Americal infantry division	Chu Lai	0.17	0.29[a]
Brigade base camp	Phuoc Vinh	0.12	0.31[a]
Average		0.55	0.67
Standard deviation		0.57	0.51

[a] Adjusted to reflect "required" usage.

The column labeled "Adjusted kW/person" in Table 5-1 incorporates the adjustments made by Keller and Gannon, the consulting engineers, to the four bases with the lowest peak loads. Keller and Gannon judged that those four bases – all with low voltage systems – had inadequate power. They adjusted power requirements upwards based on general lighting standards: 1.2 volt amperes per square foot for quarters lighting and 3.5 volt amperes per square foot for base function lighting, plus other increases for exterior lighting and special occupancy equipment.

Connected load is, in fact, a better estimator of Vietnam power usage than population. Peak power use at the seven installations averaged 50.6 percent of connected load (after adjustment), with a standard deviation of only 5 percent. The

ratio of peak to connected load ranged from a low of 42 percent at an infantry division camp to a high of 60 percent at an Army aviation base.

Data on domestic peacetime power use at all TRADOC and FORSCOM installations in FY 1987 also show that average power use per person varies widely among installations.[3] The data show, unsurprisingly, that current peacetime domestic power use is higher than wartime use in Vietnam. Total FY 1987 power use (as opposed to peak use) averaged 0.71 kW per person per installation. The standard deviation is very nearly equal to the average, which makes the average a poor estimator. Peak use was probably about 1.0 kW per person, higher than Vietnam peak use of 0.67 kW per person.

When population and power usage are the only data available, the statistical technique of linear regression yields a better estimator than a simple average. The technique calculates a fixed factor and a variable factor; it also provides measures to evaluate the reliability of the estimate. Applying linear regression to our domestic installation data, we find that a typical FORSCOM or TRADOC installation uses a fixed amount of about 1.9 megawatts (MW) plus a variable amount of 0.45 kW per person. That relationship explains about 62 percent of the variation in power usage. The remaining 38 percent is explained by other determinants.

Because population should not be the sole parameter for calculating electric use where other data are available, the Army's Mobile Electric Power Program recently developed a methodology to size TacGen units based on equipment: the Belvoir Generator Allocation Program (BGAP). That methodology is used to calculate the TacGen requirements based on the actual equipment allotted to each unit (as specified in the Army's TO&Es) together with a probability assessment of its use.

The Navy develops power requirements for its ships based on power-using equipment rather than population. It estimates the actual loads that would be experienced under five different operating conditions: anchor, shore, cruising, functional, and emergency. Generators are sized to meet the maximum load under each condition. The Air Force uses a similar approach for aircraft. Load profiles are

[3] Department of the Army; *Facilities Engineering and Housing Annual Summary of Operations*, Vol. III. Office of the Assistant Chief of Engineers. FY 1987.

developed for 10 operating conditions ranging from ground maintenance to emergency.

The private industry approach to sizing electrical requirements is more ad hoc. Most commercial, domestic, and industrial buildings do not have well defined, pre-established electrical loads and require the flexibility to change the number and types of equipment in a given facility. The national electric code (NEC) promulgates general demand factors for different types of facilities and the electrical capacity is calculated accordingly. Certain buildings with a significant need for reliable power – such as hospitals and nuclear power plants – establish their back-up and/or emergency power needs at or even above their connected load.

In the Army, these other methods are not appropriate. Oversizing electrical requirements will result in a waste of valuable people, fuel, and parts resources. Undersizing would result in Army units unable to perform or would significantly restrict their mission. Therefore, the Army needs a method that focuses on the real determinants of electric power to successfully define its prime power requirements.

PROPOSED MODEL APPROACH

Any approach for sizing an electrical generator to satisfy electrical requirements of an installation, base, fixed facility, or commercial building should start with an analysis of the electricity-consuming equipment that will be served by the generator. When all the equipment and its electrical characteristics are known, some simple electrical relationships can be applied to quantify the total load or connected load of that installation, base, or fixed facility. Assigning probabilities to the equipment can simulate the user's load profile during a normal operating day to determine peak load. To calculate OCONUS prime power requirements, the PPRM has three major components that (1) calculate connected load, (2) simulate peak load conditions, and (3) allocate electrical generators to satisfy the prime power requirement. PPRM calculates CONUS requirements using a combination of regression factors based on population and data on existing electric capacity.

Connected Load

The model calculates the total system power requirement or connected load for 60 Hz, 400 Hz, and/or 50 Hz frequencies and direct current requirements by summing the real and reactive load of individual pieces of power-consuming

equipment and calculating the system's power factor. The system's connected load can then be obtained from these factors. Appendix B contains an explanation of the electrical characteristics and formulae that the PPRM uses to calculate the system electrical loads.

Peak Load

Since all electric devices will not be turned on at the same time, estimating a peak load requirement is a better method for allocating the most appropriate-sized generator. The model determines the peak load experienced by the system by simulating the on/off status of each of the individual pieces of equipment. Each piece of equipment is assigned a probability to simulate the systems load profile. The probabilities in the prototype model are based on Vietnam and Bright Star data.

The model uses the Monte Carlo technique to simulate equipment use which results in a peak load determination in kilovolt-amperes (kVA) per base cluster, or other fixed facility. The calculations for peak load are the same as previously discussed for the system's connected load.

Generator Allocation

After calculating system-connected and peak loads, the model then assigns the properly sized electric generator(s) to satisfy the consumption needs. Too-high single loads or starting current surges can create problems to the generators and system as a whole; therefore, if either exceeds a percentage of the connected load, the model flags those clusters or facilities for further consideration. The model provides a summary of the Army-wide prime power generator needs for selected peacetime or wartime scenarios. Because of the speed at which the model operates, users can perform sensitivity analysis by varying the conditions of a scenario to determine the optimum number and mix of generators, given acceptable confidence ranges.

CONUS Requirement

The model bases CONUS mobilization requirements on population factors because TO&E data are inapplicable. Rather than use the simple JCS average kW-per-person factors, however, the model uses linear regression factors. That is, the model assumes that peak demand at each installation with a mobilization mission consists of the same fixed (open-the-door) kW factor plus a kW-per-person factor that varies with population. The model uses a domestic peacetime fixed kW-per-

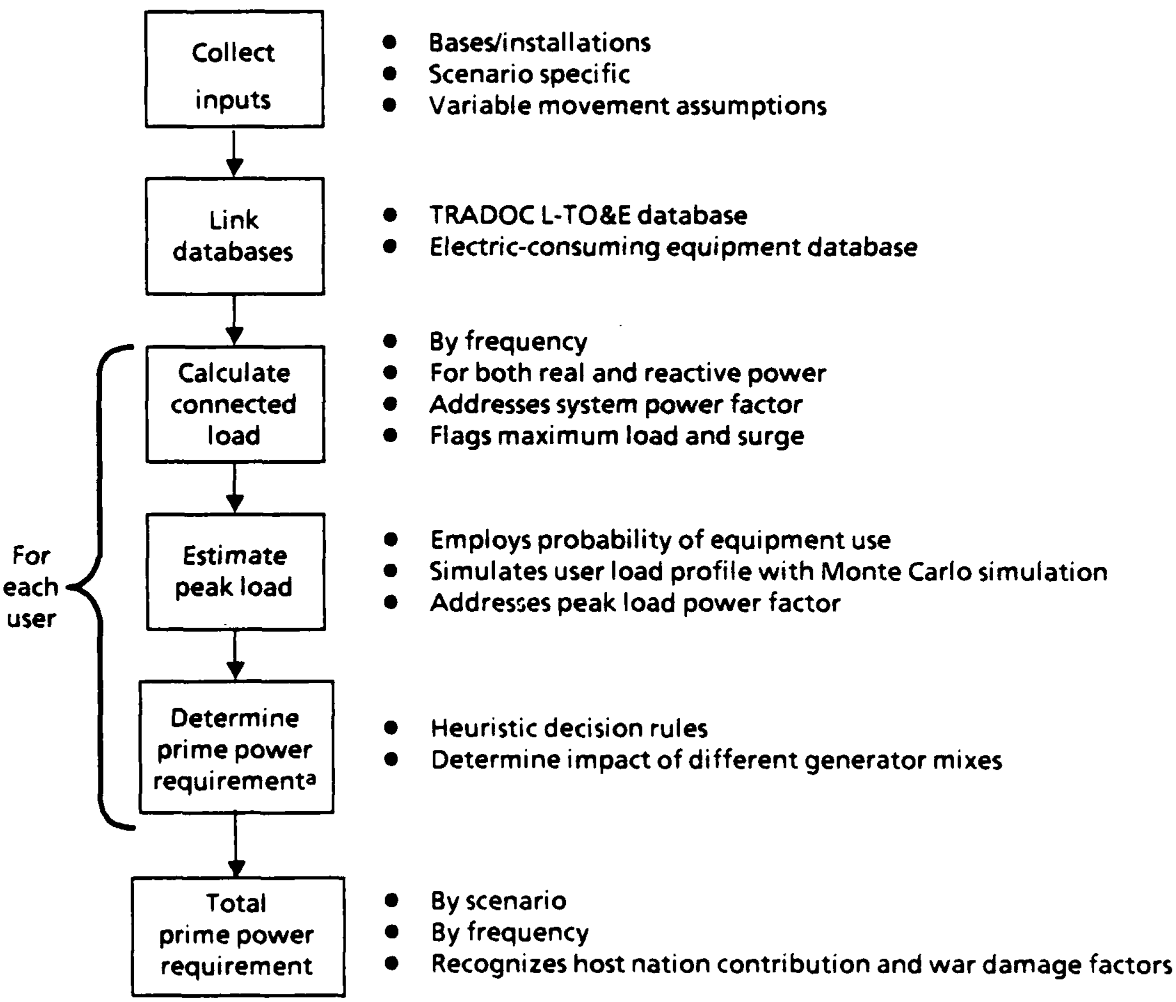
installation factor but substitutes a wartime kW-per-person-per-installation variable factor in place of a peacetime variable factor as more appropriate for mobilization. The model presents its calculated values to the user as default values; the user can substitute installation-specific estimates when appropriate.

The model estimates prime power requirements for each FORSCOM and TRADOC installation that has a mobilization mission (including Alaska and Hawaii). It requires the following installation-specific inputs: normal peak load, expected mobilization population, commercial substation capacity, and reserve generating capacity. Using those inputs plus the embedded factors, the model estimates mobilization peak load; the user – FORSCOM or TRADOC – can overwrite that calculated estimate if a better installation-specific estimate exists. The prime power requirement equals mobilization peak load minus the combination of commercial substation capacity and reserve generating capacity.

APPENDIX A

PROTOTYPE PRIME POWER REQUIREMENTS MODEL

Figure A-1 summarizes the prototype Prime Power Requirements Model (PPRM). The prototype model estimates peak loads for each user. The determination of a generator mix by user and the total generator mix are enhancements that are not yet complete.



[a] Enhancements to prototype; to be developed.

FIG. A-1. PRIME POWER REQUIREMENTS MODEL COMPONENTS

The prototype model (Version 1.0) requires an IBM PC™ or IBM PC-compatible computer with a hard disk. The PPRM constitutes a series of databases plus an "engine" that links those databases and performs the calculations. The prototype model is written in Pascal – a compiled computer language. (Pascal is a high-level computer language used to create independent computer programs; the user needs neither a Pascal compiler nor any knowledge of Pascal to operate the PPRM.)

MODEL INPUTS

The prototype PPRM requires that the user specify two inputs at each run of the model: minimum movement frequency and conflict intensity. Those inputs can be varied for each run of the model to test the sensitivity of prime power requirements to various assumptions.

In addition, the PPRM requires scenario-specific databases as inputs. Those consist of lists of bases and installations specific to a particular scenario. We discuss those databases in more detail below.

MODEL OUTPUTS

The prototype PPRM displays two basic sets of outputs. The first displays connected and peak-load data by user. We summarize those outputs in Table A-1. The second output is a distribution table showing numbers of users versus load size, as summarized in Table A-2.

LINKING DATABASES

The prototype PPRM uses several individual databases containing information on bases and facility types, the numbers and types of units in the bases, the number and types of electricity-using equipment in units and facilities, and finally, electrical operating data for electricity-using equipment. The prototype model first links the databases in order to determine how much equipment exists within each user group. Once it has linked the databases, the model calculates the required load. We discuss the contents of the various databases and the ways in which the model links them together below.

TABLE A-1

OUTPUT I: CONNECTED AND PEAK LOADS BY USER

	50 Hz	60 Hz	400 Hz	DC	Total[a]
Connected load					
System power factor	0.0	0.99	0.87	–	–
Load (kVA)[b]	0.0	573.0	126.6	3.3	702.9
Max load (kVA)	0.0	31.1	8.7	0.6	31.1
Max surge (SkVA)	0.0	62.2	17.3	1.1	62.2
Peak load					
System power factor	0.0	0.99	0.87	–	–
Load (kVA)	0.0	499.4	96.2	3.3	598.9

Note: Sample data for Corps Main Command Post.

[a] Total is not simple sum of parts due to frequency conversion.

[b] kVa = kilovoltampere.

TABLE A-2

OUTPUT II: PRIME POWER REQUIREMENTS BY LOAD SIZE

Load size	Number of user groups
500 - 750 kVA	2
750 - 1,000 kVA	7
1,000 - 1,500 kVA	1
1,500 - 2,000 kVA	0
Total PP user groups	10

Base Database

The base database is an input, since base characteristics such as frequency of movement, location, and quantity are scenario-dependent. The model's data input routines allow the user to choose from a list of standard units.

The database requires the following inputs: base name (if any), echelon, location, movement frequency, and cluster quantity. Movement frequency is the

expected number of days that the base will remain in one spot; base quantity is the number of bases in a given operating plan or scenario.

For each base, the database also requires one or more of the following sets of inputs: unit name, standard requirement code (SRC), and unit quantity. The name and SRC are chosen from an existing list within the model. Unit quantity represents the number of each unit type per base.

The model ignores bases that move more frequently than the minimum movement frequency (or whose quantity equals zero). All input bases remain in the database, however, for use in sensitivity analysis.

Facility Database

Like the base database, the facility database is an input since the number and types of facilities are scenario-dependent.

The database will comprise the following fields: facility name, location, and facility quantity. The model's input routines let the user choose from a list of standard facility types.

Table of Equipment Database

The table of equipment database contains data on the number and types of electricity-consuming (*not* electrical-generating) equipment in each standard Army unit. The source of that data is the unit Tables of Organization and Equipment (TO&E). TRADOC's L-edition TO&Es are a particularly valuable data source because they reflect the most up-to-date projections of equipment requirements. The prototype model does not use modified TO&Es specific to individual units.

The database is part of the prototype model, not an input. It comprises the following fields: SRC, line identification number (LIN), and item quantity. Item quantity is the number of a particular item per unit.

The model links lists of equipment with units; the linkage occurs on the SRC field of the unit and the equipment databases. The model then creates a temporary database with the following fields: cluster ID, LIN, and item quantity. Item quantity is the number of items per cluster; it is calculated simply by multiplying the number of items per unit times the number of units per base.

Electrical Equipment Database

The electrical equipment database contains data on the electrical properties of Army equipment. The model uses the database originally developed for the Belvoir Generator Allocation Program (BGAP). The database comprises many fields of which PPRM uses the following subset: LIN, name, power (kW), preferred voltage, preferred frequency, preferred phase, current (amperes), power factor, surge factor, and rated temperature (for air conditioning and heating).

The model links the electrical equipment database with the temporary cluster/ TO&E database via the LIN field. Once it has made that final linkage, the model has the data it needs to calculate connected load, peak load, and system power factors for each user.

CALCULATING CONNECTED LOAD

The model calculates connected load by frequency for each type of base and facility. For each base or facility, the model sums all the kW real power requirements and the reactive power requirements (kVAR) per item. Using those sums, it calculates the system power factor and the resulting connected load. (We discuss those calculations in more detail in Appendix B.)

The model also finds the maximum individual load in kVA and the maximum starting surge in kVA. If either quantity exceeds a percentage of the total connected load, the model flags that base/facility for special consideration.

ESTIMATING PEAK LOAD

Since all items are not likely to be turned on at the same time, peak load rather than connected load is a better guide to sizing generator requirements. The model calculates peak load by assigning a probability to each class of equipment representing its chance of being on at a particular time of day.

The prototype model uses Vietnam data on the relationship between connected load and peak load at combat and combat support bases. Future enhancement of the prototype model should incorporate experience from Army exercises and engineering expertise to refine those probabilities. We suggest using a structured rank-ordering technique – such as the Expert Choice™ method – with daily demand profiles for

different categories of equipment developed by groups of Army electric-power experts.

The model uses a Monte Carlo simulation technique to simulate equipment use. Peak load is calculated for the peak time of day using the same relationships used for calculating connected load.

Having calculated connected load and peak load (plus the system power factor for both peak and connected load) for each base or facility, the model then displays those quantities. The model then multiplies the load per user group times the number of user groups and displays a distribution of load sizes. That is, the model shows how many users can be satisfied with 500 kVA generators, how many with 750 kVA generators, etc., and how many require multiple generators in various combinations.

APPENDIX B

CALCULATING ELECTRICAL LOADS

INTRODUCTION

This Appendix gives a brief overview of the principles and concepts of electricity, electric power, and electrical generators. It also describes the techniques incorporated in the Prime Power Requirements Model (PPRM) to calculate the electric load for sizing the prime power requirements for Army bases and fixed facilities (i.e., maintenance and supply depots, ports of debarkation, railway stations, etc.).

ELECTRICITY

The fundamental components of electricity are current, voltage, and impedance. These three closely related components define electric power and electric energy. Designing electric generating and distribution systems, especially with alternating current, requires a thorough understanding of these basic concepts.

Current, Voltage, and Impedance

Current is a measure of the quantity of electrical charge that flows past a given point in a conductor. This can be related to the volume of water flowing through a pipe or hose. However, unlike flowing water, the velocity of current is considered instantaneous. Current is measured in amperes and 1 ampere is defined as 6.251×10^{18} electrons passing a given point in a conductor in 1 second. Current is supplied in two ways: alternating current (AC), and direct current (DC). Both will be discussed in the following section.

Electricity has a tendency to flow whenever positive and negative charges collect on opposite terminals. This tendency or force is called electromotive force (EMF), potential difference, or voltage. Voltage can be thought of as electric pressure much the same as the pressure that water produces when it is forced through a pipe. Similarly, voltage produced by a generator causes current to flow when a conductor is connected between the potential difference of the charged

terminals. Voltage is directly proportional to the current it produces. Voltage is measured in volts (V).

When current flows through materials, a resistance or friction opposes its flow. In alternating current circuits, the opposition to flow is called impedance. Impedance has two components: resistance and reactance (see Equation 2). In circuits where only direct current flows, the reactance is zero, so the circuit impedance is purely resistive. Resistance, reactance, and impedance are all measured in ohms.

The impedance of a circuit is a function of the materials and the cross sectional area through which the current flows. Generally, metals exhibit lower resistance to current and are therefore used as conductors (i.e., copper wire). Materials that exhibit high resistance to current are used as insulators (i.e., rubber, glass, and plastics).

Equation 1, known as Ohm's Law, defines the basic relationship between voltage, current, and impedance for AC and DC circuits. Simply stated, current varies proportionally with voltage and inversely with impedance. Equation 2 defines the relationship between impedance, resistance, and reactance.

$$I = V/Z \qquad \text{[Eq. 1]}$$

$$Z^2 = R^2 + X^2 \qquad \text{[Eq. 2]}$$

where:

I = Current (amps)
V = Voltage (volts)
Z = Impedance (ohms)
R = Resistance (ohms)
X = Reactance (ohms).

Direct and Alternating Current

Direct current flows continuously through a circuit and typically has a uniform voltage. In other words, direct current does not change direction.

Alternating current varies with respect to both time and direction. The oscillating nature of the current and voltage is a product of the rotating generators

that produce it. Each oscillation or cycle per second is defined as a hertz (Hz). As can be seen in Figure B-1, AC assumes a sinusoidal wave form. For the most part, voltage and current follow the same curve and are in phase, however, impedance in AC circuits has a reactive component in addition to resistance that causes a phase shift between the voltage and current. The phase shift can be represented by an angle (Θ). The cosine of this angle is called the power factor (PF). Power factors will be discussed further in the following section on calculating power requirements. Nearly all electric loads have a lagging power factor (i.e., current lags voltage) or a unity power factor. Synchronous motors, synchronous condensors, and capacitors are exceptions that have slightly leading power factors.

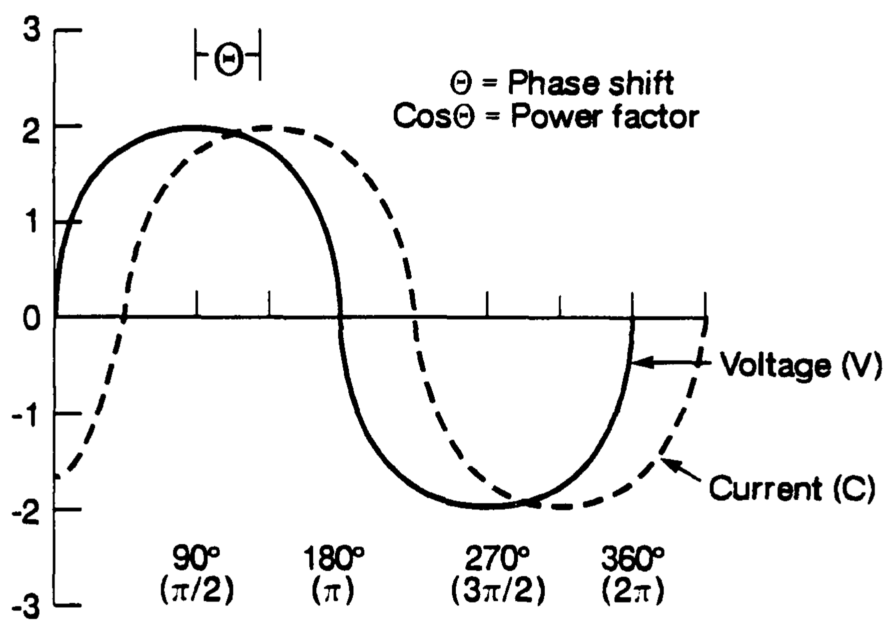


FIG. B-1. ALTERNATING CURRENT

AC current can be distributed much more efficiently than direct current because the oscillating nature of AC merely excites adjacent electrons. Direct current requires that electrons be "pushed" through a conductor resulting in high voltage losses over distance.

ELECTRICAL POWER

Electrical power (P), measured in watts (W), is the rate at which electric energy is consumed or work is done. However, the watt is a small quantity in relation to system electrical loads, so the kilowatt (kW) is normally used for measuring the power magnitude of systems. Calculating power for DC and AC circuits requires different formulae. In the AC circuit, voltage and current may be out of phase with each other depending on the type of load. Therefore, power is the product of voltage and the portion of current that is in-phase with the voltage. This is called real power and is measured in kW. Real power is the portion of the total power that performs the actual mechanical work. The simple product of full voltage and full current is called apparent or total power and is measured in kilovolt-amperes (kVA) by convention. The vector difference between apparent and real power is called imaginary power and is measured in kilovolt-ampere-reactance (kVAR). Real power divided by apparent power is the power factor. Equations 3 through 10 illustrate the relationships, and Figure B-2 shows the vector relationship of total, real, and reactive power.

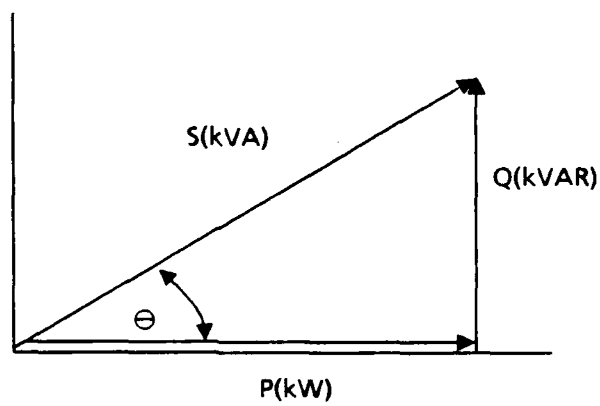


FIG. B-2. POWER VECTORS

For DC:

$$P = VI \qquad \text{[Eq. 3]}$$

For AC (1-Phase loads):

$$P = VI(\cos\Theta) = VI(PF) \qquad \text{[Eq. 4]}$$

$$Q = VI\,(sin\Theta) \qquad \text{[Eq. 5]}$$

$$S = P + jQ \qquad \text{[Eq. 6]}$$

$$S^2 = P^2 + Q^2 \qquad \text{[Eq. 7]}$$

For AC (3-Phase loads):

$$P = \sqrt{3}\ VI\,(PF) \qquad \text{[Eq. 8]}$$

$$Q = \sqrt{3}\ VI\,(sin\Theta) \qquad \text{[Eq. 9]}$$

Power Factor:

$$PF = P/S \qquad \text{[Eq. 10]}$$

where:

P = Real power (watts)
V = Voltage (volts)
I = Current (amperes)
Cos Θ = Power factor (PF) or angle that voltage is out of phase with current
Q = Reactive or imaginary power (volt-ampere-reactance)
S = Total or apparent power (volt-amperes).

For purely resistive loads, the power factor equals 1.0 and S(kVA) equals P(kW).

Connected and Peak Load

The power requirement for a city, building, Army installation, or Army unit can be calculated utilizing the above equations. The summation of all the electricity-consuming devices for an installation measured in kW divided by the system power factor is called the connected load. The electrical system's power factor can be calculated with Equations 11 and 12, which are an extension of the trigonometric relation of Figure B-2.

$$PhaseShift_{(system)}(\Theta) = tan^{-1}\frac{\sum kVAR}{\sum kW} \qquad \text{[Eq. 11]}$$

$$PowerFactor_{(system)} = COS(\Theta) \qquad \text{[Eq. 12]}$$

where:

ΣkW = The system's total real power
$\Sigma kVAR$ = The system's total reactive power.

Once the system's power factor is known, Equation 13 can be used to calculate the system's connected load for each unique base cluster, fixed facility, and other requirements.

$$ConnectedLoad_{(system)}(kVA) = \frac{\sum kW}{PowerFactor_{(system)}} \qquad \text{[Eq. 13]}$$

Not all system devices will be consuming electricity at the same time. For instance, heating and cooling equipment will not be on at the same time. Therefore, simply calculating connected load as a method for sizing generator requirements may overstate the actual total requirement at a given time of day. The computer model developed by LMI corrects for this by simulating the load profile of the electricity users. The load profile will be factored against the connected load to determine the base cluster's or fixed-facility's peak load requirement. The peak load will determine the appropriate generator size to satisfy the electrical requirements. A contingency factor may be added to the peak load to allow growth and a safety margin for the system. Generally, peak load occurs when air-conditioning or electric heating equipment are operating since these are normally the largest loads on the system.

Electric Load Profile

When sizing a generator, it is important to look at the load profile of the equipment, buildings, or installations over the entire day. The load profile can best be determined using actual power consumption data, but it can also be simulated by calculating the total system requirements from the equipment that will be connected to the system and multiplied by the probability that the equipment will be on or off

throughout the day. Industry generally assumes that peak load will be a straight percentage of connected load depending on the use of the facility. For instance, for residential housing, peak load may be at 60 percent of connected load whereas nuclear power plants may be sized at 100 percent or more of connected load. These simple industry standards are not appropriate for determining peak loads on military bases, installations, or other fixed facilities since the equipment used there is oftentimes unique and its use is dependent on wartime scenarios. Nor is it appropriate to overstate the electrical requirement since valuable Army resources will be wasted. A simulation of load profiles to determine the system's peak load is appropriate for such applications.

Other Considerations

The computer model also accounts for other considerations in electrical system design such as surge factors and the maximum single load. Generally, the model limits the size of any individual load (including starting surge) to a percentage of the total system's operating capacity. This will significantly reduce voltage and current dips at the system's rated power factors.

ELECTRICAL GENERATORS

Electricity is generated according to Faraday's Law of electromagnetic induction. Stated briefly, voltage can be created or induced by moving a conductor through a magnetic field. When using a turning motor, the conductor or magnetic field can be rotated which will induce a voltage of alternating polarity and thus alternating current. The frequency of the alternating current is therefore a function of the speed at which the driving motor is turning. In the United States, AC power is produced at 60 cycles per second or hertz. Other countries provide other frequencies.

Alternating current is produced by AC generators or alternators. For the most part, DC power is produced by an AC generator with a device that rectifies and filters the AC to produce DC. Batteries and DC generators produce the only direct source of DC. It is necessary for some types of consuming equipment to convert AC to DC to operate properly. This is accomplished by running the AC through a rectifier and a capacitor to achieve a wave form closely resembling DC. The rectifier and capacitor combination is generally known as a DC power supply.

Essentially, electric motors and electric generators are the same piece of equipment except that motors convert electric power input into useful mechanical output and generators convert mechanical input into useful electrical output. Practically any type of engine or turbine can be used to power a generator. In fact, a motor-generator is a motor (generator) and a generator (motor) on the same shaft. Motor-generators can be used to convert frequencies up or down.

APPENDIX C

WORLDWIDE ELECTRIC POWER FREQUENCY AND VOLTAGE STANDARDS

In the United States, standard commercial power is provided at 120 volts (V) and 60 hertz (Hz) by convention. Therefore, nearly all equipment produced in the United States or for the United States require power at this frequency and voltage. Other countries have chosen, for various reasons, to supply different frequencies and voltages as their commercial supply. In many countries, these differences present a problem when U.S. equipment must operate from local power.

Table C-1 shows the electric power, frequency, and voltage standards for Western Europe, the Mid-East, Africa, the Far East, and Oceania. The table indicates the main frequency and voltages supplied by each nation and whether that power is compatible with U.S. equipment that requires 120 V, 60 Hz power. When it is not compatible, conversion of the local power is required.

Electric power conversion can be accomplished in several ways. Transformers can be used when voltage alone needs to be changed. Generally, equipment that requires a 120-V source can withstand about a 10 percent voltage difference (approximately 110 V – 130 V). In those nations where voltage is within that range, no voltage conversion is required. Power converters or motor-generator sets can be used if frequency only or frequency and voltage conversion are required. It should be noted that some 60-Hz equipment can tolerate a 50-Hz supply at the same voltage, but other equipment may be frequency-sensitive. Frequency and/or voltage conversion can be accomplished at the main power source for all equipment or at the individual pieces of equipment that require it. The effects of 50-Hz power on equipment rated for 60 Hz vary. These are some of the effects:

- AC motors will run at 83 percent of normal speed.
- Solenoids, transformers, and all magnetic circuit devices will operate at higher, perhaps unusable, temperatures.
- Watt-hour and other electric measuring devices will not operate properly.

- Radar equipment, clocks, and other frequency-sensitive equipment will operate but will be in error.
- All 60-Hz equipment should be monitored for temperature increases. It may be necessary to derate the voltage of 60-Hz equipment when operating at 50 Hz to lower the temperature.

TABLE C-1

WORLDWIDE FREQUENCIES AND VOLTAGES

Country	Frequency (Hz)	Voltage (V_{LN}/V_{LL})[a]	Conversion required for U.S. 60-Hz, 120-V equipment[b]	
			Frequency	Voltage
Western Europe				
Belgium	50	127/220 220/380	Yes	
Denmark	50	220/380	Yes	Yes
France	50	115/200 127/220 220/380	Yes	
West Germany	50	220/380	Yes	Yes
Ireland	50	220/380	Yes	Yes
Italy	50	127/220 220/380	Yes	
Luxembourg	50	120/208 220/380	Yes	
Netherlands	50	220/380	Yes	Yes
United Kingdom	50	240/415	Yes	Yes
Iceland	50	220/380	Yes	Yes
Austria	50	220/380	Yes	Yes
Finland	50	220/380	Yes	Yes
Norway	50	230	Yes	Yes
Portugal	50	220/380	Yes	Yes
Sweden	50	127/220 220/380	Yes	Yes
Switzerland	50	220/380	Yes	Yes
Greece	50	220/380	Yes	Yes
Spain	50	127/220 220/380	Yes	

Source: *Analysis and Evaluation of Requirements for U.S. Army Nontactical Generators*, U.S. Army Corps of Engineers Feb 1981. pp. 2-4, 2-5, 2-10, 2-11, 2-12, 2-14 and 2-15.

[a] Line to neutral voltage (V_{LN}) is given first followed by line to line voltage (V_{LL}).

[b] For ease in reading the table, only Yes answers are noted, blanks indicate no conversion is needed

TABLE C-1

WORLDWIDE FREQUENCIES AND VOLTAGES (Continued)

Country	Frequency (Hz)	Voltage (V_{LN}/V_{LL})	Conversion required for U.S. 60-Hz, 120-V equipment[a]	
			Frequency	Voltage
Mid-East/Africa				
Egypt	50	220/380	Yes	Yes
Israel	50	230/400	Yes	Yes
Iran	50	220/380	Yes	Yes
Iraq	50	220/380	Yes	Yes
Lebanon	50[b]	110/190	Yes	
Jordan	50	220/380	Yes	Yes
Syria	50[b]	115/200	Yes	
Saudia Arabia	50 60	127/220 230/400	Yes	
Bahrain	50 60	230/400 110/220	Yes	Yes
Cyprus	50	240/415	Yes	Yes
Kuwait	50	240/415	Yes	Yes
Oman	50[b]	220/440	Yes	Yes
Turkey	50	220/380	Yes	Yes
Libya	50[b]	127/220 230/400	Yes	
Morocco	50	115/200 127/220	Yes	
Kenya	50	240/415	Yes	Yes
Algeria	50	127/220 220/380	Yes	
Tunisia	50	127/220 220/380	Yes	
Nigeria	50	230/415	Yes	Yes
Zaire	50[b]	220/380	Yes	Yes
Angola	50	220/380	Yes	Yes
Cameroon	50	127/220 220/380	Yes	
Gabon	50[b]	220/280	Yes	Yes
Ghana	50[b]	220/400	Yes	Yes
Somalia	50[b]	220/380 110/220	Yes	

[a] For ease in reading the table, only Yes answers are noted, blanks indicate no conversion is needed.

[b] Frequency not stable enough for sensitive equipment, such as electric clocks, in most cities.

TABLE C-1

WORLDWIDE FREQUENCIES AND VOLTAGES (Continued)

Country	Frequency (Hz)	Voltage (V_{LN}/V_{LL})	Conversion required for U.S. 60-Hz, 120-V equipment[a]	
			Frequency	Voltage
Far East/Oceania				
Japan	50 & 60	100/200	Yes	
Korea, South	60	100/200		
Peoples Republic of China	50[b]	220/380	Yes	Yes
Bangladesh	50[b]	230/400	Yes	Yes
India	50	330/380 230/400	Yes	Yes
Indonesia	50[b]	127/220	Yes	
Malaysia	50	240/415	Yes	Yes
Pakistan	50	220/380 230/400	Yes	Yes
Philippine Islands	60	110/220 115/230		
Thailand	50	220/380	Yes	Yes
Okinawa	60	120/240 100/200		
Taiwan	60	110/220		
Hong Kong	50	200/346	Yes	Yes
Australia	50	240/415	Yes	Yes
New Zealand	50	230/400	Yes	Yes

[a] For ease in reading the table, only Yes answers are noted, blanks indicate no conversion is needed.

[b] Frequency not stable enough for sensitive equipment, such as electric clocks, in most cities.

APPENDIX D

EXISTING ARMY PRIME POWER ASSETS

Figures D-1 through D-3 illustrate three representative examples of existing Army prime power generators. All three produce 750 kilowatts (kW) at either 60 hertz (Hz) or 50 Hz, use diesel fuel, and are enclosed in weatherproof, sound-attenuating housings.

Figure D-1 shows a skid-mounted unit that produces less than 85 decibels (db) at 30 feet. It includes transformers and switchgear that make it self-sufficient for isolated operation. The unit weighs 88,000 pounds.

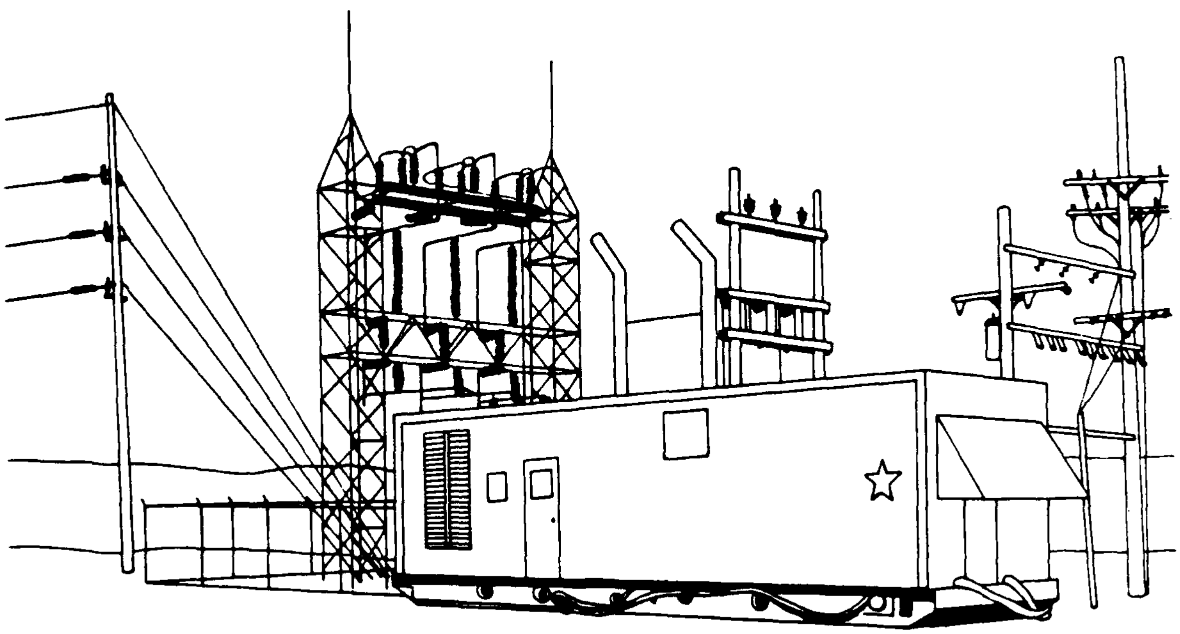


FIG. D-1. SKID-MOUNTED PRIME POWER GENERATOR

Figure D-2 is a gas-turbine (diesel-fired) 750 kW unit. As illustrated, it is air-transportable on all standard Air Force cargo aircraft. It produces less than 85 db at 15 feet and weighs 36,000 pounds.

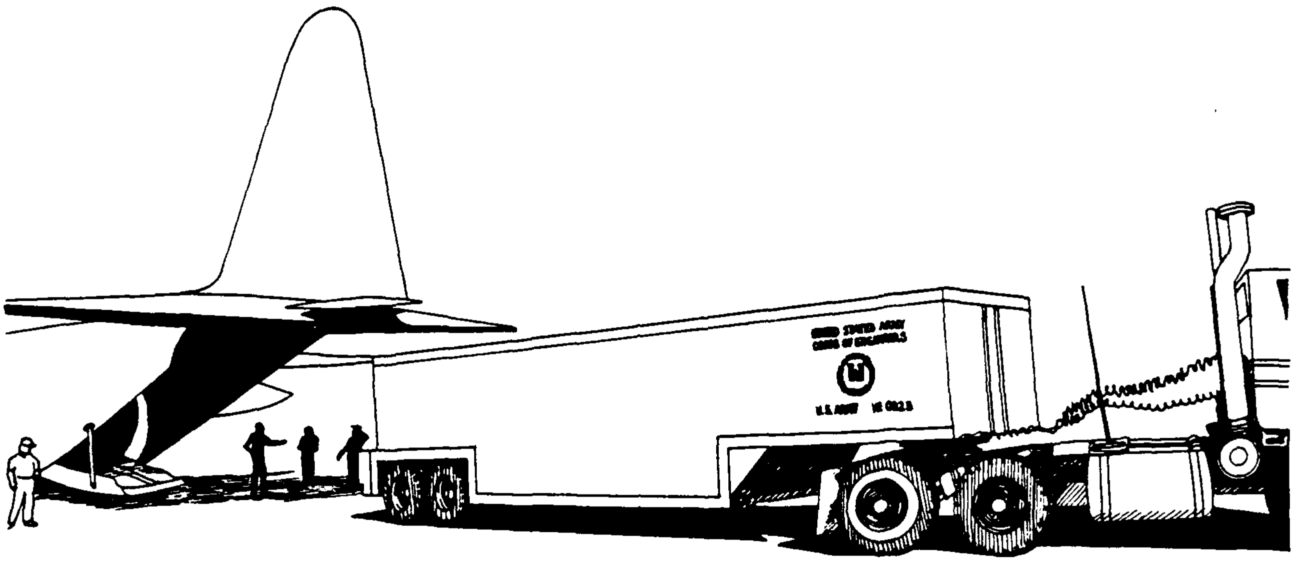


FIG. D-2. WHEELED, TRAILER-SIZED PRIME POWER GENERATOR

Figure D-3 shows a fairly compact unit that is trailer-mounted and can be towed at up to 20 miles per hour on improved roads. Despite its relatively small size and weight (25,000 pounds), it still produces less than 85 db at 25 feet.

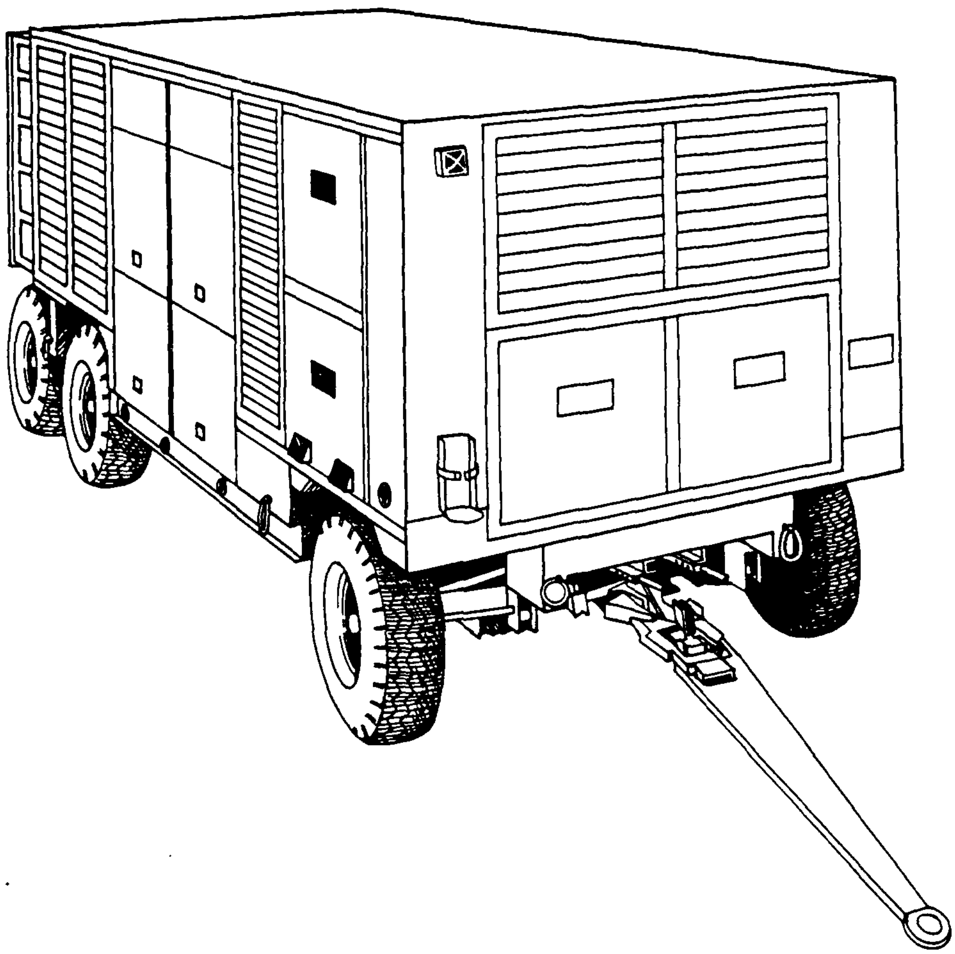


FIG. D-3. COMPACT, TRAILER-MOUNTED PRIME POWER GENERATOR

APPENDIX E

SUGGESTED REVISION TO ARMY REGULATION 700-128

PRIME POWER PROGRAM OBJECTIVES

The objectives of this program are to:

- Provide theater commanders during military contingencies with resource-effective electrical power generation for unit groups in secure areas within the Communications Zone where mobility is not critical and where sufficient commercial (host nation) power of requisite quality is unreliable or unavailable, thereby conserving vital Army resources – fuel, manpower, and tactical generators – for combat requirements.

- Provide electrical power generation to installation commanders outside the combat theater to support units in transit, including surge electrical capacity for Army installations during mobilization.

- Provide the loan of Prime Power Program (P^3) assets, including manpower, to satisfy high priority electrical power requirements for special purposes, including the following:

    - Provide security of electrical supply to military installations during emergency interruptions.

    - Provide military and civilian disaster relief.

    - Supplement existing electrical power sources during temporary planned interruptions.

    - Provide temporary electrical power for military construction and research and development projects when commercial power is unavailable.

- Store and maintain Prime Power Program electrical generating plants and associated transmission/distribution equipment.

- Train, equip, and support the personnel necessary to (1) install, test, operate, and maintain organic P^3 equipment, and (2) repair, operate, and maintain standard commercial equipment in overseas theaters.

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The Army cannot be sure whether it has enough prime power generators to provide electricity during wartime. It has reason to believe it may not.

The uncertainty – the possible deficiency – should not be tolerated. Prime power is essential. The alternatives will not suffice. Commercial utilities are not available everywhere and are too vulnerable in wartime. Tactical generators consume too much fuel, demand too much maintenance, and wear out too fast for general usage.

The barrier to overcoming the problem is the Army's inability to produce a sound estimate of the requirement. The current estimating method is based on an outdated and incomplete mission statement for prime power generators and employs a single, outdated, kilowatt-per-person planning factor. The mission should be restated to include:

- Overseas, provide reliable, mobile, and resource-efficient power to groups of Army units and essential installations behind the front combat zone.
- In the United States, support large, rapid population increases in Army installations during mobilization.

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ABSTRACT (Continued)

- In the United States, provide emergency power to Army and other critical installations when commercial power distribution is disrupted.

The requirements calculation should, to be more reflective of real-world forces, be based on scenario-specific simulation of peak-time power consumption byselected Army units and installations.

These changes should be implemented by the Army's Engineering and Housing Support Center. Only then will the Army be in a position to rectify any prime power deficiencies.